SPECTRAL ABSORPTION OF LIGHT BY DEEP WATER OF LAKE BAIKAL

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Received December 10, 1996

This paper presents some measurement results on light absorption by the water from Baikal Lake. The measurement technique is also described. Analysis is presented of a possibility to widely use a few-parameters model for describing the absorption spectra of water from Baikal Lake. Temporal variations and the dependence of the parameters on the depth are considered.

INTRODUCTION

Water of natural reservoirs is a complex multi-component physicochemical and biological system. It is impossible now to carry out a complete theoretical analysis of the optical properties of such a system. So the results of direct measurements of the optical parameters of natural media and development of phenomenological models based on such data is of a special significance.

Various models[1] (statistical and physical) have been developed and successfully used for describing the optical properties of sea waters. At the same time, only one attempt has been undertaken for the model description of light absorption spectra of water from Baikal Lake.[2] An estimate is given in this paper of the possibility to widely use the idealization[2] which is based on the most precise measurements of light absorption spectra of the water of Baikal Lake.

MEASUREMENT TECHNIQUE AND RESULTS

We have carried out routine observations of the optical properties of water of the lake during 1993–1996 in the area where the neutrino telescope (NT) is constructed (51°50′N, 104°20′E; 3.5 km far from the Ivanovskii cape) in the framework of the project on creation of deep-water neutrino telescope on Baikal Lake.

The BURKHAN meter of the primary hydrooptical parameters[3] was developed for enabling complex investigations of the optical state of water of the lake.

The channel of measuring the absorption index $\varkappa$ in the BURKHAN device consists of the meter of irradiance (PMT–130 with a light collector) and a movable point light source (halogen lamp KGMN–27). Measurements of the spectra $\varkappa(\lambda)$ in the range of 350–700 nm were carried out in 16 narrow spectral intervals isolated with the interference filters. Movement of the source was used for the automated calibration of the device, that makes it possible to obtain the metrologically reliable results.

The photon flux through the sphere of radius R surrounding an isotropic point source of monochromatic radiation decreases with increasing optical depth in a homogeneous scattering medium[1] according to the law

$$F = F_0 \exp(-\xi\tau), \tag{1}$$

where F_0 is the photon flux emitted from the source; $\tau = \varkappa R$ is the optical length of absorption.

In the general case, the factor ξ is the complex function of absorption and scattering properties of the medium ($\xi = 1$ if no scattering occurs). Natural water is characterized by a high anisotropy of scattering (scattering occurs mainly in the forward direction). The factor ξ is close to 1 for such media. One can write a solution to the radiation transfer equation for the point isotropic source in the small-angle approximation taking into account the photon distribution over free paths, in the form

$$F = F_0 \exp(-\tau)\,\frac{\rho}{\sinh(\rho)} \quad \text{for} \quad \rho = \tau\sqrt{P/2} \ll 1. \tag{2}$$

The parameter $P = \sigma\,\hat{\gamma^2}/\varkappa$ depends on the optical properties of the medium. Here σ is the scattering index; $\hat{\gamma^2}$ is the mean square of the single scattering angle,

$$\hat{\gamma^2} = \int_{-1}^{1} \gamma^2\,\chi(\gamma)\,\mathrm{d}\cos(\gamma),$$

where $\chi(\gamma)$ is the scattering phase function, γ is the scattering angle.

Expanding Eq. (2) into a series over ρ and neglecting the higher orders of ρ we obtain from Eqs. (1) and (2)

$$\xi - 1 \approx \tau\,P/12.$$

Measurements of the irradiance at large distances from the point source showed that $P \le 0.2$ for the deep water of Baikal Lake.[5] We can neglect the contribution from scattering ($\xi - 1 < 0.01$) at the distances $\tau < 0.6$ corresponding to the maximum value of P.

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Let us now write using this approximation the expression for the count rate $N_i(R)$ of single-photoelectron pulses from the PMT–130 in the experiments with the filter of the number i ($i = 1, ..., 16$), using Eq. (1)

$$4\pi R^2 N_i(R) = SW\int_{\lambda_1}^{\lambda_2} I_0(\lambda)\exp(-\varkappa(\lambda)R)T_i(\lambda)\eta(\lambda)d\lambda, \quad (3)$$

where $I_0(\lambda)$ is the spectral density of the photon flux from an actual source; $T_i(\lambda)$ is the product of the transmission coefficients of a filter, window, and the light collector; $\eta(\lambda)$ and S are the quantum yield and the area of the photocatode of the PMT–130, respectively; W is the probability of the photoelectron detection; λ_1 and λ_2 are the boundary wavelengths of the interval.

Selective absorption of light in the medium leads to the change of the spectral composition of nonmonochromatic light with the increasing distance. This effect (Forbs) can significantly distort the results of spectral measurements.

As follows from Eq. (3) the exact equality

$$\varkappa(\lambda_i) = -d\ln(N_i(R)R^2)/dR \quad (4)$$

is fulfilled only at $T_i(\lambda) = \delta(\lambda - \lambda_i)$ that is equivalent to the monochromatic radiation.

Actual light filters have a finite width of the transmission band. The result of measurement in this case is related to some effective wavelength $\tilde{\lambda}_i$. In the general case, $\tilde{\lambda}_i$ differs from the wavelength at the transmission maximum of the filter λ_i by the value $\delta\lambda_i = \tilde{\lambda}_i - \lambda_i$. The values $\tilde{\lambda}_i$ were calculated based on the spectral parameters of the emission, filters, PMT and on the "zero approximation" spectrum $\varkappa(\lambda = \lambda_i)$ obtained directly from Eq. (4).

The absolute value $\delta\lambda_i$ is small for the filters used with the FWHM $\Delta\lambda_i < 10$ nm ($\delta\lambda_i < 0.5\Delta\lambda_i$). However, this effect is a systematic one, and the neglect of it leads to significant distortions of the spectra. The systematic error in determining $\varkappa(\lambda)$ can reach 5–7% at some portions of the spectrum that significantly exceeds the random error of 2–3% characteristic of our measurements.

After introducing relevant corrections, we can assert that the relative error in measuring $\varkappa(\lambda)$ does not exceed 5% at any point of the spectral interval.

Estimation of the values $\varkappa(\tilde{\lambda}_i)$ and the rms errors $\sigma_{\varkappa_i}$ has been carried out by the least squares method. Then we took into account both the mean values and the errors in measuring $N_i(R_0 + j\Delta R_i)$ at every point on the distance grid ($j = 0, ..., J \geq 10$). The spread of N_i values about the mean value is caused by the statistical nature of measurements, variations of the source existence and the detector sensitivity during the measurements as well as by the errors in positioning. The initial distance $R_0 = 1$ m was chosen for the source to be considered as a point one. The step ΔR_i varied from 0.1 to 0.5 m depending on the filter used (transmittance of the medium). The points satisfying the aforementioned condition of the small contribution of the light scattering $\varkappa(\tilde{\lambda}_i)(R_0 + J\Delta R_i) < 0.6$ were taken into account when calculating $\varkappa_{bw}(\lambda)$.

Measurements with different filters were carried out in an arbitrary sequence. Reproducibility of the data and the absence of variations in the medium properties during the spectral measurements were controlled by performing additional measurements in one or two spectral intervals.

An example of absorption spectrum of deep water of Baikal lake $\varkappa_{bw}(\lambda)$ obtained by the technique described above is shown in Fig. 1. The light absorption index of water from the Baikal Lake varied by one order of magnitude in the spectral range 350–700 nm. As is seen from the figure, the decrease of the spectrum at $\lambda > 500$ nm is caused by absorption of light by pure water.

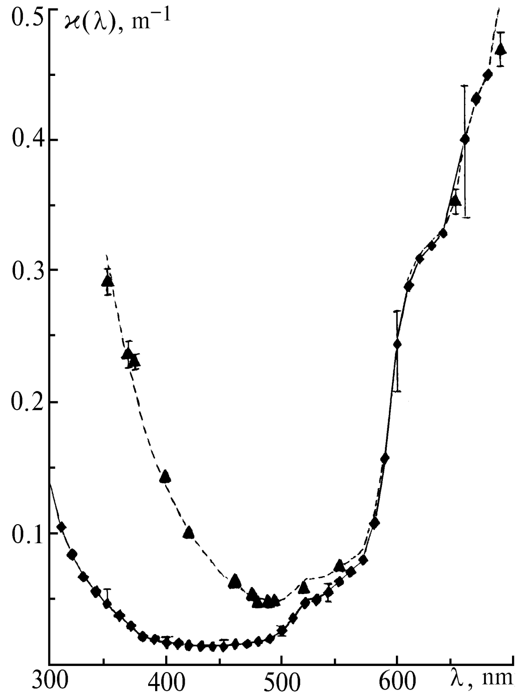

FIG. 1. Light absorption spectra of water: triangles –Baikal water, results of our measurements (Southern Baikal, depth of 1000 m, *May 18, 1993); diamonds –pure water*[10]*; solid line – linear interpolation of the data of Ref. 10; dashed line – model spectrum, explanation is given in the text of the paper.*

The absorption by admixtures dominates in the range $\lambda < 450$ nm. The minimum of absorption is near $\lambda = 490$ nm. This shape of the spectrum is characteristic of the deep zone.

The results of measurements and calculations of the absorption spectra of the near-surface water of the lake are presented in Ref. 6.

MODEL OF ABSORPTION PROPERTIES OF THE BAIKAL WATER

The few-parameter model[2] was proposed to describe the shape of the spectral behavior of light absorption of the deep water of Baikal Lake. This model takes into account the contribution of the optically most active components of natural water: pure water and so-called "yellow substance" (YS) which is the complex of organic molecules produced by the plankton organisms decomposition.[7] The absorption spectrum of YS in the visible and near UV spectral range exponentially increases as the wavelength decreases[8]:

$$\varkappa_{YS}(\lambda) \sim \exp(-\mu\lambda), \quad (5)$$

what makes its typical color.

The value $\mu = 0.015$ nm^{-1} is usually used for the model description of the absorption spectrum of YS of sea water. The exponent μ is in our case an independent variable characterizing qualitatively the composition of YS.

In this paper we do not consider the depth range $H < 100$ m, in which the water of the lake is optically inhomogeneous. Hence, in contrast to Ref. 9, the contribution of phytoplankton pigments into the light absorption is neglected. Such a simplification is possible, because, as is noted in Ref. 1, the correlation is observed between the YS concentration and the quantity of pigments, and the relative contribution of the pigments into the light absorption at $H \geq 100$ m does not normally exceed 1%.

Thus, we use the following model for description of the absorption spectra of deep water of Baikal Lake

$$\varkappa_{bw}(\lambda) = \varkappa_{cw}(\lambda) + \varkappa_{YS}(\lambda) =$$

$$= \varkappa_{cw}(\lambda) + \varkappa_{YS}(\lambda = 390\text{ nm})\exp(-\mu(\lambda - 390\text{ nm})), \quad (6)$$

where $\varkappa_{cw}(\lambda)$ is the absorption spectrum of pure water, $\varkappa_{YS}(\lambda = 390\text{ nm})$ is the absorption index of YS at the wavelength of 390 nm ($\varkappa_{390}$). The index $\varkappa_{390}$ is the parameter proportional to the YS concentration.

THE SPECTRAL ABSORPTION OF LIGHT BY PURE WATER

Strange though it may seem, principal difficulties of the model representation (6) are related to the absence of precise measurements of the light absorption spectra of pure water.

It is known that the absorption spectra $\varkappa_{cw}(\lambda)$ essentially differs from the spectrum of water vapor due to strong interaction between the molecules. The broadening and overlapping of the bands, displacement of the bands to the long-wave range, and the effective increase of absorption occur. For making accurate theoretical calculations of light absorption by liquid water it is necessary to determine the position of energy levels of the condensed system, that seems to be impossible now.

Let us consider the experiment. Optical properties of pure water are studied experimentally since the end of the last century. Nevertheless, they are only poorly studied up to date. Indeed, the results of measuring $\varkappa_{cw}(\lambda)$ in the range $\lambda < 500$ nm obtained by different authors can differ by orders of magnitude.[1]

As the authors of Ref. 1 think, it is related to the difficulties of obtaining ideally pure water and keeping the necessary cleanness during measurements. In our opinion, the extremely high transparency of the pure water at $\lambda < 500$ nm is also important here. According to the data from Ref. 1, the free path of a photon before its absorption in water can reach 500 m. It is clear that absolute measurements of such a small quantity (less than 0.2% of the total photon flux is absorbed at the path of 1 m) are very difficult under laboratory conditions when it is necessary to take into account the scattering effects correctly.

Having the choice problem, we think that it is possible to use the data of the critical review of the optical properties of pure water.[10] The review presents the most reliable, in the authors opinion, results of measuring and estimating the absorption index of pure water $\varkappa_{cw}(\lambda)$ in the wavelength range 200–800 nm. The spectrum $\varkappa_{cw}(\lambda)$ obtained in Ref. 10 is shown in Fig. 1. As is seen from the figure, as the wavelength decreases in the range $\lambda < 500$ nm, the contribution of pure water into the total absorption decreases. The influence of the ambiguity in the values $\varkappa_{cw}(\lambda)$ on the parameters of our model also decreases. Despite of this fact, we agree with the authors of Ref. 10, that it is necessary to carry out reliable measurements of the spectral absorption of pure water at $\lambda < 500$ nm.

ABSORPTION SPECTRUM OF YS OF BAIKAL LAKE WATER

We define the absorption spectrum of YS according to Eq. (6) as a difference between the measured values of the light absorption of water from Baikal Lake and the absorption spectrum of pure water

$$\varkappa_{YS}(\tilde{\lambda}_i) = \varkappa_{bw}(\tilde{\lambda}_i) - \varkappa_{cw}(\tilde{\lambda}_i).$$

Figure 2 presents a typical example of the absorption spectrum of YS of deep water from Baikal Lake. The values of the light absorption index of pure water at the effective wavelengths $\tilde{\lambda}_i$ were obtained by linear interpolation of the data from Ref. 10. It is seen that the spectrum of YS has an exponential shape with small deviations

$$\varkappa_{YS}(\lambda) = \varkappa_{390}\exp[-\mu(\lambda - 390\text{ nm})].$$

Using the least squares method and taking into account the errors in measuring $\varkappa_{bw}$ at each point of the spectrum and estimates of the accuracy of determination of $\varkappa_{cw}$ presented in Ref. 10, we have calculated the values of the parameters and obtained the estimates of their random errors ($\varkappa_{390}$= = (0.141±0.002) m^{-1}, and μ=(0.0166±0.0003) nm^{-1}) for the spectrum presented).

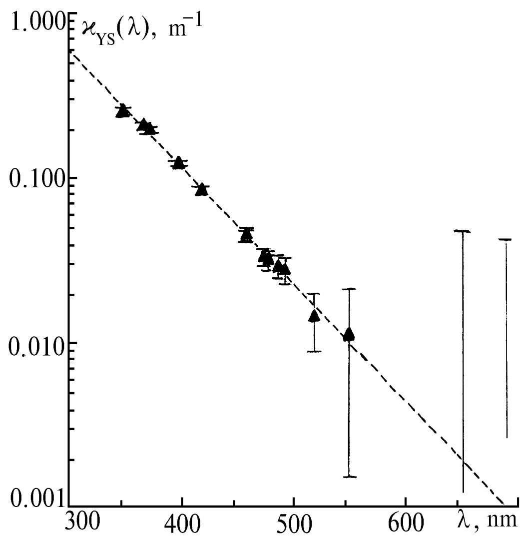

FIG. 2. Spectral absorption of light by "yellow substance" of the Baikal water; triangles – difference between spectral absorption of Baikal water and pure water (see Fig. 1); dashed line is the approximation of the spectrum by the dependence of the form $\varkappa_{390}$ exp(–μ(λ – 390 nm)). *The values of parameters are:* $\varkappa_{390}$ = 0.141 m^{-1} *and* μ = 0.0166 nm^{-1}.

The experimental data were processed using the technique described above. The criterion of selection of the data for the subsequent analysis was the availability of six measurement points of $\varkappa_{bw}(\lambda)$ in the range λ < 500 nm. Two parameters were put into correspondence to every spectrum. By substituting the values $\varkappa_{390}$ and μ into Eq. (6), one can obtain continuous distribution of the light absorption index of Baikal water in the wavelength range 350–700 nm.

COMPARISON WITH THE EXPERIMENT

The results of measurements of the absorption index $\overset{\text{exp}}{\varkappa_{bw}}(\tilde{\lambda}_i)$ in different years at arbitrarily selected depths are presented in the Table I. The calculated spectra $\overset{\text{calc}}{\varkappa_{bw}}(\lambda)$ are also presented there.

Analysis of data presented in the table shows that the rms deviation of the calculated spectra from the experimental data

$$\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\Delta\varkappa_i/\overset{\text{calc}}{\varkappa_{bw}}(\tilde{\lambda}_i)\right)^2},\ \left(\Delta\varkappa_i = \overset{\text{exp}}{\varkappa_{bw}}(\tilde{\lambda}_i) - \overset{\text{calc}}{\varkappa_{bw}}(\tilde{\lambda}_i)\right),$$

is 5.2% (5.8; 3.5%) at the mean random error of the experiment 2.7% (3.1; 2.3%) at the depths of 200 m (500, 1000 m). Since the systematic error of the experiment, which we have not taken into account, is ~1% according to our estimates, one can consider such a correspondence of the theory and the experiment as satisfactory.

TABLE I. Comparison of the calculated values of the light absorption index of Baikal water $\overset{\text{calc}}{\varkappa_{bw}}(\tilde{\lambda}_i)$ *with the experimental results* $\overset{\text{exp}}{\varkappa_{bw}}(\tilde{\lambda}_i)$

$\tilde{\lambda}_i$, nm	$\overset{\text{exp}}{\varkappa_{bw}}$, m^{-1}	$\overset{\text{calc}}{\varkappa_{bw}}$, m^{-1}	$\sigma_\varkappa/\overset{\text{exp}}{\varkappa_{bw}}$, %	$\Delta\varkappa^*/\overset{\text{calc}}{\varkappa_{bw}}$, %	$\overset{\text{exp}}{\varkappa_{bw}}$, m^{-1}	$\overset{\text{calc}}{\varkappa_{bw}}$, m^{-1}	$\sigma_\varkappa/\overset{\text{exp}}{\varkappa_{bw}}$, %	$\Delta\varkappa^*/\overset{\text{calc}}{\varkappa_{bw}}$, %	$\overset{\text{exp}}{\varkappa_{bw}}$, m^{-1}	$\overset{\text{calc}}{\varkappa_{bw}}$, m^{-1}	$\sigma_\varkappa/\overset{\text{exp}}{\varkappa_{bw}}$, %	$\Delta\varkappa^*/\overset{\text{calc}}{\varkappa_{bw}}$, %
351	–	–	–	–	0.299	0.315	2	–5	0.421	0.389	4	8
369	0.253	0.252	2	1	0.236	0.231	2	2	0.272	0.282	2	–4
374	0.234	0.231	3	1	0.221	0.211	2	5	0.259	0.257	2	1
400	0.152	0.153	2	–1	0.139	0.137	2	1	0.157	0.163	3	–4
420	0.112	0.115	2	–3	0.098	0.101	2	–3	0.111	0.118	3	–6
459	0.070	0.070	2	0	0.059	0.060	2	–2	0.065	0.067	3	–3
460	0.071	0.069	2	4	0.061	0.060	3	1	0.072	0.066	3	9
475	0.059	0.059	3	0	0.049	0.051	3	–3	–	–	–	–
479	0.056	0.057	2	–2	0.049	0.050	3	–2	0.055	0.054	4	2
488	0.055	0.053	3	4	0.047	0.047	2	2	–	–	–	–
494	0.051	0.053	2	–4	0.049	0.047	2	5	–	–	–	–
519	0.062	0.068	2	–8	0.061	0.063	2	–4	0.057	0.064	4	–11
550	0.074	0.077	2	–3	0.075	0.074	2	1	0.072	0.074	4	–3
651	0.342	0.357	2	–4	0.350	0.356	2	–2	0.377	0.356	2	6
691	0.419	0.516	9	–19	0.477	0.516	2	–8	0.492	0.516	3	–5
H	200 m				1000 m				500 m			
Date	22.03.1993				18.05.1995				04.04.1996			
$\varkappa_{390}$	0.159 ± 0.002 m^{-1}				0.141 ± 0.002 m^{-1}				0.173 ± 0.004 m^{-1}			
μ	0.0156 ± 0.0002 nm^{-1}				0.0166 ± 0.0003 nm^{-1}				0.0176 ± 0.0006 nm^{-1}			

* $\Delta\varkappa = \overset{\text{exp}}{\varkappa_{bw}} - \overset{\text{calc}}{\varkappa_{bw}}$.

The greatest difference between the experimental and calculated data is observed at the point $\lambda = 519$ nm. Analysis of the spectra shows that this difference is systematic (experimental values $\varkappa_{bw}$(519 nm) are always less than the calculated ones).

In our opinion, it can be related to the preference which the authors of Ref. 10 give to the results obtained by Morel[11] in comparison with the data obtained by Tam.[12] The method of laser optoacoustic spectroscopy used in Ref. 12 is free of many uncertainties characteristic of the standard techniques, and has quite good accuracy ~10%. According to Ref. 12, the results $\varkappa_{cw}(\lambda)$ in the range 515–546 nm are systematically lower (by 10%) than the results from Ref. 11 and much better agrees with our measurements. Unfortunately, we have the only light filter in this range, and can not unambiguously choose between the data from Ref. 11 or Ref. 12.

High sensitivity of the model proposed for optical characteristics of pure water at $\lambda > 500$ nm and small experimental error allow us to hope for improving the accuracy of determining $\varkappa_{cw}(\lambda)$ in this wavelength range by 3–5 times. Our main task for the nearest future is to carry out more detailed measurements of $\varkappa_{bw}(\lambda)$ simultaneously in the short-wave and long-wave spectral ranges.

In general, taking into account the aforementioned remarks, one can suppose that the model considered well describes the absorption spectra of deep water of Baikal Lake, in the error limits of 4–6%, and can be used for the subsequent analysis. One can consider deep water of the Baikal Lake as an optical system consisting of two components, pure water and YS, with the same degree of ambiguity.

DEPTH BEHAVIOR AND TEMPORAL VARIATIONS OF THE OPTICAL PARAMETERS

Depth dependences of the model parameters should correspond to the variations of the quantitative and qualitative composition of the absorbing admixture with depth.

As is seen from Fig. 3*a*, the range of variation of μ with depth is small being about ±10%. The average value over depth is $\hat{\mu} = (0.0166 \pm 0.0007)$ nm^{-1}. The estimate of $\hat{\mu}$ well agrees with the mean value μ for $H \geq 100$ m calculated from the extinction spectra $\varepsilon(\lambda)$ in the range $300 \text{ nm} < \lambda < 400$ nm, $\mu = (0.0161 \pm 0.0048)$ nm^{-1} (Ref. 13). Measurements of $\varepsilon(\lambda)$ were carried out using samples of Baikal water. At the same time, the statement of the authors of Ref. 13 about a significant range of variation of μ seems to be poorly validated. Indeed, if one takes into account the error in determining μ [σ_μ ~ 0.05 nm^{-1} (oral message by P.P. Sherstyankin)], then all the values[13] are within the limits $\pm 2\sigma_\mu$. Relatively high error in the results[13] is caused mainly by short measurement path ($R = 10$ cm). Close value $\mu = (0.0162 \pm 0.0002)$ nm^{-1} was obtained for $H = 1000$ m by one of the authors[12] in early measurements of $\varkappa_{bw}(\lambda)$. The estimate of depth variations of μ (± 0.001 nm^{-1}) is also given there.

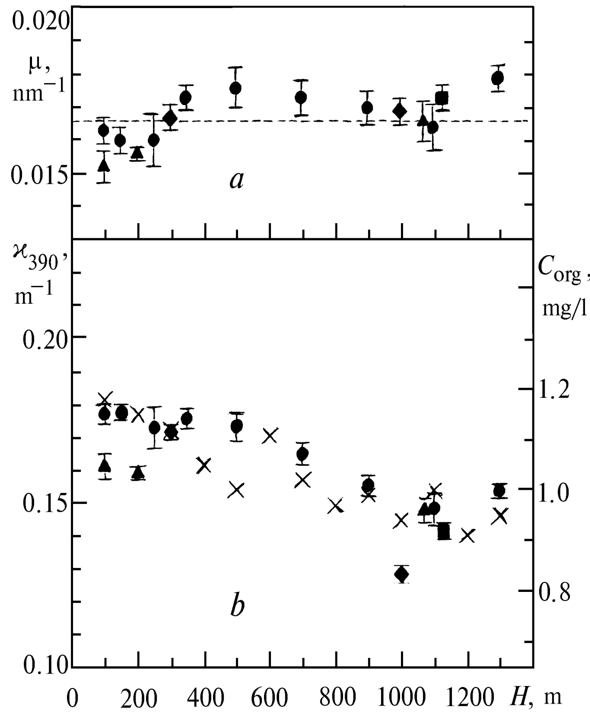

FIG. 3. Depth behavior of the parameters: triangles –results of measurements carried out since March 22 till April 8, 1993; diamonds – since March 25 till April 15, 1994; square – March 29, 1995; circles – April 4 and 5, 1996; crosses – content of C_{org} in the water of Southern Baikal (averaged over 1986–1989)[20]; dash – depth-average value of the parameter μ.

The aforementioned data do not contradict our results. Unfortunately, the list of not so numerous studies of the optical properties of YS of Baikal water is completed.

Let us present for a comparison the parameters of YS of the freshwater lakes of Australia ($\mu = (0.016 \pm 0.002)$ nm^{-1}) and New Zealand[14] ($\mu = (0.019 \pm 0.002)$ nm^{-1}).

The assumption was made in Ref. 15 based on measurements of the absorption spectra of YS of the ocean water, that there are two fractions of YS: one of them (low-molecular) determines the absorption of YS at $\lambda < 500$ nm, and another one (high-molecular) – at $\lambda > 500$ nm. It is stated there that the composition of the first fraction is qualitatively the same in different types of water including ocean, sea, rivers and lakes, in spite of variations. The value $\mu = (0.017 \pm 0.001)$ nm^{-1} for this fraction is also close to our estimate of $\hat{\mu}$.

In general, one can conclude that the method proposed for determining the parameter μ from the absorption spectra measured *in situ* is one of most precise. Variations of the parameter μ with depth are small, that is indicative of practically the same composition of YS of the Baikal water at the depths more than 100 m.

The near-surface water, as well as the areas which are subject to the influence of a river sink can be an exception.

Indeed, the shape of the spectra measured near the lake surface, is different from the deep ones. We observed the break near $\lambda = 500$ nm in the absorption spectra of admixtures at $H \le 10$ m. Possibly, it is related to the increase of the relative contribution of such components as phytoplankton, coarse-disperse suspension or high-molecular fraction of YS into the total absorption. However, we do not present any estimate here because of a small amount of measurements at $H < 100$ m and significant effect on the results of high spatial and temporal in homogeneities in the optical properties.

Thorough investigations are needed in a wide spectral range by means of low-inertial instruments with the short measurement path for an adequate model description of the optical properties of near-surface water of the lake. Then the two-parameter model can be used as first approximation.

On the average the parameter $\varkappa_{390}$ decreases by 20% with depth (Fig. 3*b*). One can select the plateau (H = 100–350 m) where the variations of the parameter are small; the range of uniform decrease (H = 350–1100 m) and the point H = 1300 m, where the increase of the parameter in the near-bottom zone is seen, in the depth behavior of the parameter $\varkappa_{390}$ in 1996. The depth of the place of measurements was 1370 m. The separation of the zones is also seen in the depth dependences of the parameter μ (Fig. 3*a*) and the extinction index ε (Ref. 16).

We think such vertical structure of $\varkappa_{390}$ to be a manifestation of the areas with different hydrodynamic properties. In the first area, the lower boundary of which can reach 300–400 m in March, weak density stratification is observed.[17] The convective mixing of water should occur there and equalize the YS concentration. The YS concentration in the central zone with the stable vertical stratification decreases due to aggregation, flocculation, sorption and other processes. Large-scale circulation, bringing the water from the small depth with the enhanced YS concentration, essentially affect the near-bottom area.

The first description of the optical structure of water from Baikal Lake (from the results of measuring ε) isolating three zones (upper, deep and near-bottom) and indication of the dynamical nature of their origin is given in Ref. 16.

It is clear,[18] that the destruction of the organic admixture to smaller fragments leads to a increase of absorption in the short-wave spectral range. In our case it is equivalent to the increase in the parameter μ. One can explain the structure of μ observed in Fig. 3*a* by different "age" of the water. Indeed, the water medium at the depth $H < 300$ m mainly contains slightly destructed admixture (the values μ are minimal). The time of replacement of the deep water with the near-surface one significantly increases[19] in the range $H > 300$ m. This leads to the increase of relative contribution of the short fragments of organic molecules into the total absorption and to corresponding increase of μ.

The shape of depth structure of the parameters μ and $\varkappa_{390}$ depends on the velocity of transfer of the organic matter and the time of its decomposition. So spectral measurements of $\varkappa_{bw}(\lambda)$ can become a new method for studying the processes of substance and energy transfer in the Baikal Lake.

It is interesting to reveal the relation between YS and the concentration of organic substance that is usually characterized by the content of organic carbon C_{org}. Using the data from Ref. 20, we have constructed the dependence $C_{org}(H)$ averaged over 1986–1989 on the same scale for water of Southern Baikal (12 km from Palovinnyi cape) (see Fig. 3*b*). One can see good agreement of the behaviors of C_{org} and $\varkappa_{390}$ with depth. Formally calculating the coefficients of linear regression ($r = 0.8$), we have obtained the possibility of estimating organic hydrocarbon content in the Baikal water from the data of hydrooptical measurements

$$C_{org}[\text{mg/l}] = (4.5 \pm 1.5)\varkappa_{390}[\text{m}^{-1}] + (0.3 \pm 0.2).$$

Such a relationship between the coefficients means that the portion of the "colored" substance in the total quantity of dissolved organics is quite big (75 ± 25)%. Refining the shape of the ratio between C_{org} and $\varkappa_{390}$ is planned in the series of simultaneous hydrooptical and hydrochemical measurements.

One can judge about the scale of temporal variations of the model parameters from the data of measurements in March and April for several of years (Fig. 3).

Seasonal variations of the absorption spectra were studied after installation of the BURKHAN device in the composition of hydrological garland of the neutrino telescope. The most long series of measurements were obtained in 1993 and 1995. Periodic measurements (once a month) of $\varkappa_{bw}(\lambda)$ at the depths of 1100 and 1000 m were carried out in these years, respectively, since March till October. The amplitude of oscillations of the parameters $\varkappa_{390}$ and μ relative to the mean values did not exceed 10%, that is indicative of high stability of the optical state of the water in the lake at great depths during the period under study.

CONCLUSION

The possibility of a wide use of a few-parameter model of the absorption spectrum of the deep water of Baikal Lake is proved based on the analysis of experimental data.

ACKNOWLEDGMENTS

Authors would like to thank the leaders of the Baikal National Park for the possibility of carrying out investigations.

We also thank N.M. Budnev for the attention he paid to the work, O.N. Gaponenko for the constructive criticism, P.P. Sherstyankin for useful notes and fruitful discussions, and all the participants and organizers of the expedition work for their comprehensive help. The work was supported by Russian Foundation for Fundamental Research (project No. 96–05–65216).

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